Linking Design and Manufacturing Domains via Web-based and Enterprise Integration Technologies

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Abstract

The manufacturing industry faces many challenges such as reducing time-to-market and cutting costs. In order to meet these increasing demands, effective methods are need to support the early product development stages by bridging the gap of communicating early design ideas and the evaluation of manufacturing performance. This paper introduces methods of linking design and manufacturing domains using disparate technologies. The combined technologies include knowledge management supporting for product lifecycle management (PLM) systems, enterprise resource planning (ERP) systems, aggregate process planning systems, workflow management and data exchange formats. A case study has been used to demonstrate the use of these technologies, illustrated by adding manufacturing knowledge to generate alternative early process plan which are in turn used by an ERP system to obtain and optimise a rough-cut capacity plan.

Keywords: Product Lifecycle Management, Enterprise Resource Planning, Product Development, Conceptual Design, Knowledge Management, Enterprise Integration

1. INTRODUCTION

One of the key industrial problems for modern manufacturers is the lack of collaboration during the early stages of product development. This problem is usually due to the following:

(1) A techniques for the rapid translation of early design ideas into an analysable form, and
(2) A meaningful manufacturing knowledge in the feedback evaluation process

The industrial impact of the above problem is felt in many areas, such as vital decision-making especially in the areas of product configuration and the responsiveness to changing markets and meeting customer requirements such as *engineered-to-order*. Therefore, it is important to interact with the customer to meet product definition during the earliest concept stage of product development. Hence, it is imperative that the Original Equipment Manufacturers (OEM), suppliers, vendors and customers can interact effectively and generate a conceptual design that is manufacturable and cost effective. The way to achieve this is by effective communication within the enterprise from the product design team and manufacturing operation.

With the advances in information and web-based technologies over the last decade, there is a shift of research towards focus on product development. Recently, a number of research projects have been undertaken to support collaborative and distributed solutions from the perspective of computer-aided design (CAD), PLM, workflow management, knowledge management and Web-based technologies. The key results of these are summarised as follows.

Xiao *et al*. (2001) developed a Web-based Distributed Production Realization (Web-DPR) system as an infrastructure to support collaborative design and manufacturing. Based on the Java remote method invocation (RMI) mechanism, agents and an event-based mechanism, the functional modules of the systems can be linked and co-ordinated effectively. However, the application is not specifically designed for conceptual design or for passing data on to process planning applications. Similarly, Qiang *et al*. (2001), developed a collaborative product design support environment based on the Internet. The key aspect of that research is allow product designers to exchange and share product data and communicate with team members to modify geometry data on particular aspects of the design, and maintain operations consistency in all the distributed cooperative sites on a wide variety of platforms. A limitation of this approach is that the macro operations can only be replayed on workstations using the same CAD software. Similarly, Xie and Salvendy (2003) developed a mechanism to co-ordinate remote members in the process of a collaborative project. Workers are able to actively obtain the constant feedback of the status and activities of members contributing to the whole set of collaborative tasks. For example, information about who the collaborators are, where they are now, and what they are doing. The authors have noted the shortcomings of this prototype system being no version control or other security features. There are some further other disadvantages relevant to real-world application such as the inability to share data with other CAD users.

To address the above limitations, Xu and Liu (2003) developed an architecture utilizing a Web-enabled Product Data Management (PDM) system in a collaborative design environment. The system was implemented using Microsoft Visual Basic and runs in the Microsoft Windows environment and the internet to allow users on a wide variety of platforms to access the product data. The research however was focused on the detail stage of the design. The authors have noted that the implementation of the system is partial and further research is needed for transforming geometry schema into the object-oriented schema. Visual Basic executables rely upon run time libraries which need to be stored on the client machine which makes it inflexible.

Li *et al*. 2004 (a) developed a client/server framework to enable a dispersed team to accomplish a feature-based design task collaboratively. In this research, the establishment of the distributed design environment is based on RMI. The process of designing a part collaboratively in the environment is centrally server based. The collaborative server can create and manage dynamic sessions which can be accessed by clients to provide a workspace to carry out collaborative design activities. Designers participating in the same session can share the same design model. The authors have noted that there are still some technical problems to be addressed. Firstly, the current information management on the server is a file system-based which can be replaced by a database system. Another issue is that the system lacked detailed visualisation information of mechanical parts in order to support web-based collaboration. However, Li *et al.* (2004 (b)) have also developed an Internet-enabled system based on Java, RMI and Web technologies to support collaborative and concurrent engineering design by integrating three functional modules, namely co-design, for Web-based visualisation and manufacturing analysis. In the co-design module, designers are equipped with co-modelling and co-modification facilities to carry out a design task collaboratively. The Web-based visualisation module provides a portal for users to view and analyse a design part conveniently. Manufacturing analysis module can be invoked by users to evaluate and optimise the manufacturing costs and the manufacturability of a design part. This system can be used for a geographically distributed design team to organise a 3D collaborative and concurrent engineering design.

The applications of workflow and knowledge management have been used to support a collaborative product development, for example, the most recent research are Madhusudan (2005) and Rodriguez and Al-Ashaab (2005). Madhusudan (2005) developed an Agent-based Process Coordination (APC) framework for distributed design process management. The approach is to embed autonomous agents in a workflow-based distributed systems infrastructure. The framework utilizes a centralized decision-making and task sharing approach to support design activities. A design process plan is executed by a centralized coordination agent with the help of service agents. However, the research does not state how the data is to be shared across different applications in the downstream processes and whether the software tool works in a real-time collaborative environment. Rodriguez and Al-Ashaab (2005) proposed a knowledge driven collaborative product development (CPD) system architecture. The research is focused on the provision of real-time manufacturing knowledge to support geographically distributed companies in making engineering decisions. The sources of manufacturing knowledge are the manufacturing process, resource capabilities, company experience, technical documents and industrial heuristic knowledge. The architecture developed as modular-based and the manufacturing knowledge model and the product model are implemented as object-oriented databases. The information is accessed using a back-end connectivity CORBA (OMG 2007). However, the authors have stated that there is no real time visualization of the geometry and therefore the design cannot be modified over the internet. Another shortcoming is that the research did not address the problem of how manufacturing knowledge can be represented in a common format to enable sharing in geographically distributed companies using different software packages.

Among the above authors, Huang *et al.* are particularly focused in collaborative product development. Huang *et al*. (2001) developed a Web-based system to manage engineering changes (ECs) in a collaborative product development activity. ECs frequently happen during a design process, and managing the ECs in a Web-based system can facilitate better information sharing, simultaneous data access and more prompt communications among team members. The system can play as a complementary tool to a PDM system to enhance its capability in the management of ECs. Meanwhile, Huang extended the Web-based system to support product design review to support a design chain (Huang and Mak, 2000; Huang 2002). The design review system functions as follows:

- Simulate an on-line central review meeting room equipped with a Virtual Reality Modelling Language (VRML) whiteboard for visualising an on-line design model.
- A review co-ordinator to provide a set of facilities for a project manager to plan the activities and resources involved in the review process.
- A Bill-of-Materials (BoM) explorer to store and share review comments and some relevant documents.

However, the above paradigm requires a series of repeatable request-download processes of static HyperText Mark-up Language (HTML) pages that are executed locally. Under this paradigm, once the download process finished, the server loses control of the relevant HTML pages. Hence, this will cause undesirable results such as the up-to-date information for design changes may not be available to other clients in the collaborative product development activities.

Among all the research discussed however, none of them particularly addressed collaborative product development and information distribution to support the early design stages with disparate technologies and software tools, which will increase the potential industrial benefits of front-end responsiveness, quality of design and production decisions. The combined disparate technologies include knowledge management using ontological technique supporting by PLM, ERP, aggregate manufacturing modelling, workflows management and eXtensible Markup Language (XML) data exchange format.

2. THE PROPOSED SOLUTIONS

The aim of this paper is to present methods for the effective management of the internet-based process of communicating new product requirements and manufacturing performance evaluations. The demonstration of the case study will focus on the critical early stages of product development throughout the product life cycle using PLM, ERP and related Web-based technologies. An integration architecture for product development has been developed to facilitate bridging the gap between the application of PLM, Enterprise Resource Planning (ERP), Web-based technologies and manufacturing and design domains.

Solutions to these problems are proposed and described below. In order to meet the development in linking design and manufacturing domains, the novel aspects of the research work are:

- The ability to easily create, modify and utilise design and manufacturing knowledge during the early design phase.
- To create assembly plans for the components and evaluate the potential viability using assembly planning tool and interface with ERP tool.
- PLM which holds all design data and meta-data as well as enabling version control of design iterations and access to shared work area for the team members.
- Secure data communications technologies to allow data to flow between team members and the central repository using an activities co-ordination mechanism

The next section focuses on the implementation issues of PLM, ERP and Web-based technologies. The integration architecture forms the theoretical backbone and defines the role of the system in supporting product development in a collaborative and knowledge distributed environment. The integration architecture is designed to be used by product design, product development and manufacturing engineers to explore possible design alternatives in a Web-based environment. The main feature within the integration architecture is the introduction of an activities co-ordination mechanism to link design and manufacturing domains. In practice, the integration environment can be used in a collaborative manner by vendors, original OEMs and suppliers with deployment of different ERP and PLM/PDM systems.

3. THE PRODUCT DEVELOPMENT INTEGRATION ARCHITECTURE

The proposed integration architecture is illustrated in Figure 1. The overall integration environment is categorized into *three layers*. The first layer is the enterprise systems which consist of the PLM/PDM and ERP technologies. The second layer is the communication and data exchange mechanism. The third layer consists of the Manufacturing and Design Domains.

The architecture uses PLM systems to address design interoperability. This solution provides the functionality of different designers at different locations to access the same design collaboratively. The architecture also supports STEP-based standards for geometric models. This standards-based collaboration can work in a global, distributed, and heterogeneous design environment. In addition, PLM offers *lifecycle management* and *versioning control* for the design and the ability to see the history or 'evolution' of a design through all its iterations. Thus, this allows geographically dispersed users to co-edit CAD geometry and related tasks dynamically.

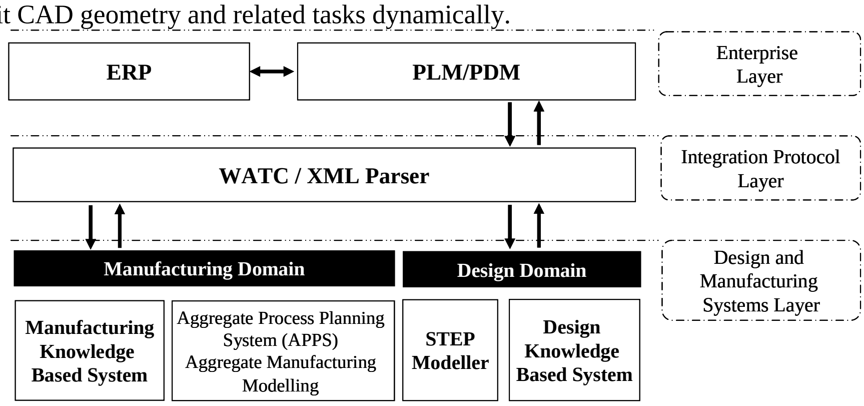


Figure 1: Overall System Integration Architecture in Product Development

3.1 The Enterprise Layer

The deployment of a PLM/PDM system provides an 'integration wrapper' for the entire integrated system. It supports an online distributed and collaborative environment with specific functions including *product data/document management*, *versioning control*, *workflows* and *lifecycle management*. The term integration wrapper denotes the ability to "wrap data and knowledge" from different domains into a common format, such as XML, so that a file can be shared within a distributed PLM environment and readily interpreted by using the terminology definitions of the ontology. The deployment of an open source ERP system is mainly used to generate capacity requirements planning based on the assembly and subassembly sequences of specific products.

3.2 The Integration Protocol Layer

An XML Parser is deployed as the interfacing technology between a PLM system and the Manufacturing and Design Domains for data interchange. This enables interchanging portions of XML documents while retaining the ability to parse them correctly and, as far as practicality is concerned, they can be formatted, edited, and processed in useful ways. The discussion of implementing the XML Parser is in Section 3.4.

3.3 The Design and Manufacturing Systems Layer

The manufacturing domain consists of an Aggregate Process Planning System (APPS) (Bramall et al, 2003) and manufacturing knowledge-based system (Cheung et al, 2006). The design domain consists of a STEP Modeller and the Design Knowledge-Based System (Aziz et al, 2005). A CAD system Pro/Desktop is used as the solid modeller to display the image of the product through a PLM Visualization functionality. An Oracle database server is also deployed to handle requests for knowledge and model information as well as deploy PLM functionalities through the use of Java Database Connectivity (JDBC).

3.4 Coordination of the Activities within the Integration Architecture

The integration of distributed and time dependent components requires a time synchronisation model. The time based co-ordination element requires the recognition of the time-dependencies of activities within a distributed team that use the stored data and knowledge. In general, a PLM system comprises; a "*Document Manager*" that contains a list of user defined *cabinets* to store data files, a "*Lifecycle*" function that defines the timing of the development stages and a "*Workflow*" function that determines what processes and interactions take place at each stage. Clearly, PLM functions can be used as a foundation for defining a time based integration wrapper as a time synchronisation model.

3.4.1 Workflows Activity Task Controller (WATC)

A novel **"**Workflows Activity Task Controller" (WATC) methodology has been defined to implement the *time based integration wrapper* concept in the interactions between generic types of PLM, ERP, Knowledge-Based systems and Process Planning functions. The methodology has been formalised in UML as shown in Figure 3. WATC sequences early design activities including *concept definition*, *design development*, *manufacturing knowledge sharing* and *automated aggregate plan* generation. WATC currently supports the following five early design stages:

1. Receive/Understand Customer Product Request and Formalise Design Specification.
2. Generation of Conceptual Design by the Product Development Team.
3. Distributed Review of the Conceptual Model and Addition of Manufacturing Knowledge and Constraints.
4. Deployment of Capability Analysis for the Prioritisation of Product Development Tasks.
5. Generation of Aggregate Process Plans (Routings) and Integrated Capacity Planning.

The core technologies behind WATC are methods to control the interactions of a PLM system, a Knowledge Based System and a Process Planning System. The implementation of WATC is centred on the lifecycle and workflow functionalities of the PLM.

The workflow starts with the customer's request for a new product or a change to an existing product as shown in Figure 2. All business processes are modelled graphically within the PLM system as flow charts. The initial stage is adding customer historical information such as previous product specifications, customer buying experience and relationships. This can be done by invoking a knowledge-based system. The knowledge-based system consists of two separate modules, one is for the design knowledge management system that captures information related to product design and design standards, and the other is for manufacturing knowledge management to capture process and resource related knowledge. The key stages of the workflow process are:

1. The primary action of the workflow is to activate the process by assigning a task to make a connection with the KBS. All the information or relevant knowledge is stored or retrieved via a Windchill PLM Cabinet function (PTC Windchill 2002). The Windchill Cabinet function is used to store product centric information and provides a method of locating information within the PLM system.
2. The second stage of the workflow is to assign a concurrent task which involves notifying team members of the development team and issues requests to the appropriate personnel to enter conceptual design data.
3. The third stage of the workflow is to review the conceptual design.
4. The fourth stage is an XML Parser mechanism which supports the interaction of data reused of the APPS and PLM systems.
5. The final stage involves capacity planning and implementation.

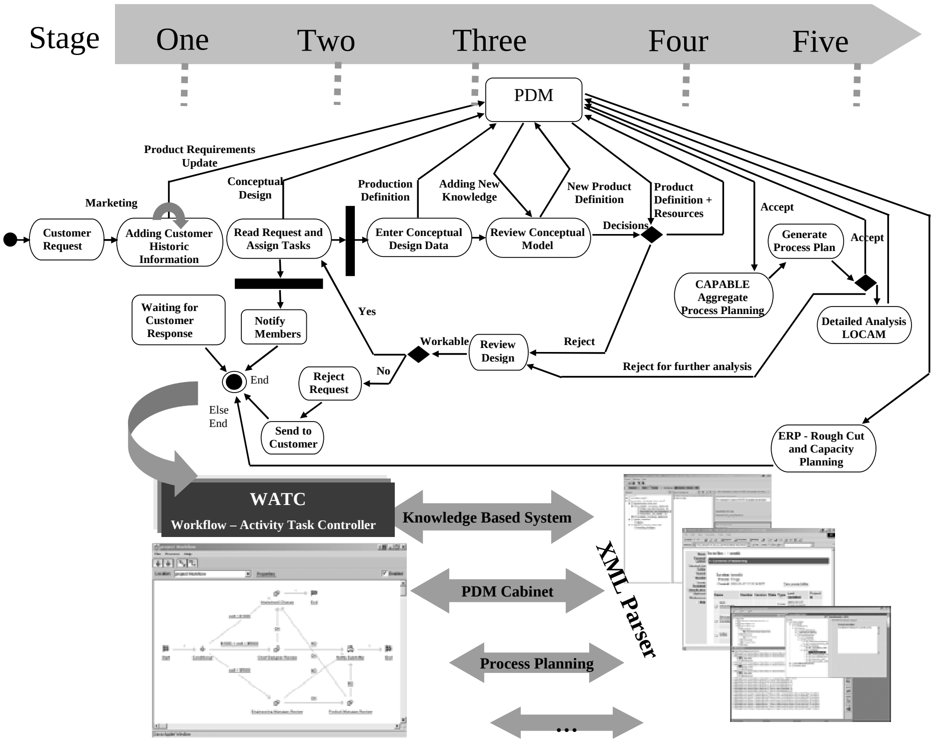


Figure 2: Time Dependency Scenario using WATC Concept

3.4.2 The XML Parser Mechanism

The XML Parser is responsible for extracting manufacturing knowledge from the XML formatted knowledge file to be reused by the process planning engine in the APPS. With the attachment of updated historical information and manufacturing knowledge, a new product definition will be generated. The product definition will be delivered to the APPS to obtain preliminary process plans. The purpose of the APPS is to allow alternative process plans (or routings) for custom parts to be generated, evaluated and improved based upon estimated *manufacturability* before committing to a fully specified product model and supplier. The new process plans (routings) are then delivered to the PLM system for Plan/Review.

3.4.2.1 Methods of Creating the XML Parser

The advantage of using an XML-formatted file is that there is a whole range of generic XML tools available to create an XML Parser for extracting the information and translating it into the required format of a proprietary tool to re-use. In this case, an XML Parser has been created for transferring the stored knowledge to the APPS. An XML Parser has been created based on the Java programming language. Figure 3 illustrates a UML Activity Diagram (Schmuller 1999) to represent the algorithm of a Java-based XML Parsers' internal methods that are used to read and extract the information (of data type string) and translate it into the format of a third party software system. The illustration represents two specific roles, the initial role is to *Prepare XML Metadata* and the second role is to *Extract XML Metadata*. Transition can take place from one role to another.

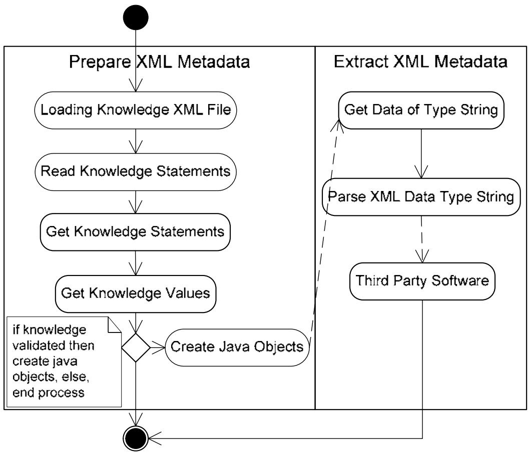


Figure 3: Algorithm of a Java-based XML Parsers' internal methods

4 CASE STUDY

4.1 Objectives and Aims

The industrial collaborator, M&J Ltd is increasing their business internationally with distributed operations and supply networks. They aim to develop greater flexibility in reacting to customer requirements on a world-wide basis and are particularly interested in the integration of design with manufacturing operations through enterprise and web-based technologies. This will give them the ability to explore remote business opportunities and distributed sourcing options. The objective of the test is to demonstrate the various software components to bridge the gap of communicating early product ideas in the design domain and the manufacturing domain to support product development processes. The aim of the evaluation was to test:

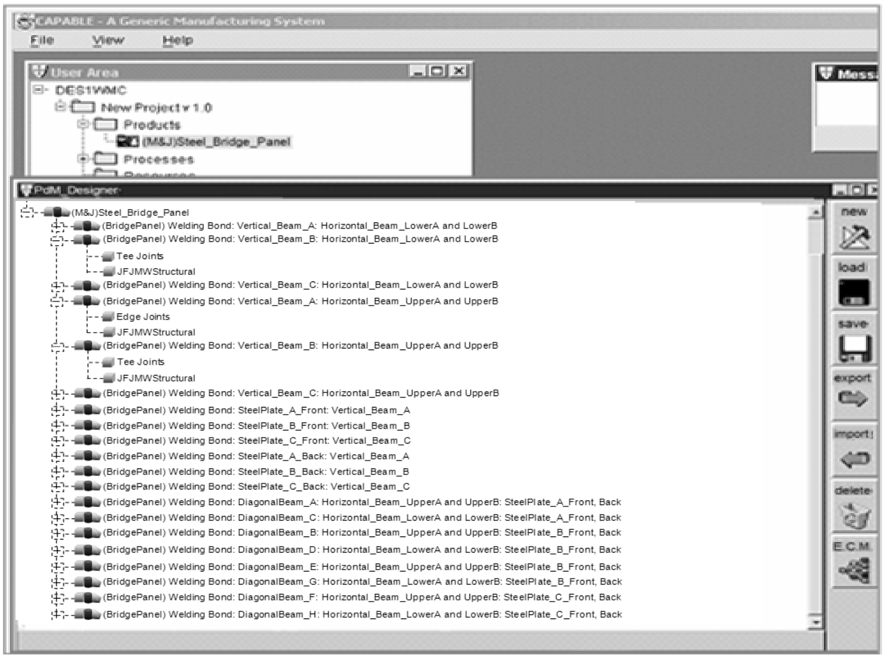
1. The technical feasibility based upon the data supplied and collected from the industrial collaborator, and
2. The WATC method to coordinate early design activities using PLM and ERP technologies, the organisational knowledge-based system and the aggregate process planning system.

The exercise concerned the evaluation of a Bailey's single steel bridge panel at the conceptual design stage and how decision support can be enhanced.

4.2 Application of the Aggregate Process Planning System (APPS)

4.2.1 The Product Description

An example of the type of weld is shown in Figure 4(b) illustrates the model of a bridge panel with EBoM (Engineering Bill of Material) configurations and the example product model modelled within the Aggregate Process Planning System. The product model represents a conceptual design stage of a single Bailey's steel bridge panel.



(b) EBoM of Product configurations

Figure 4: Product Model of a Single steel bridge panel

4.3 Factory Model Used in Testing

The factory layout of M&J is made up by a series of cells and within every cell there is a dedicated workcentre. The type of cells and workcentre(s) indicate the type of machines and their operations. Figure 5 illustrates the factory design module as modelled in the Aggregate Process Planning system. It clearly shows the position of individual cells and associated machine types. Datasheets (see Table 1) for robotic handling and welding tools were used to specify process parameters for the robotic centres, giving a range of tools that would be able to perform all handling and welding operations.

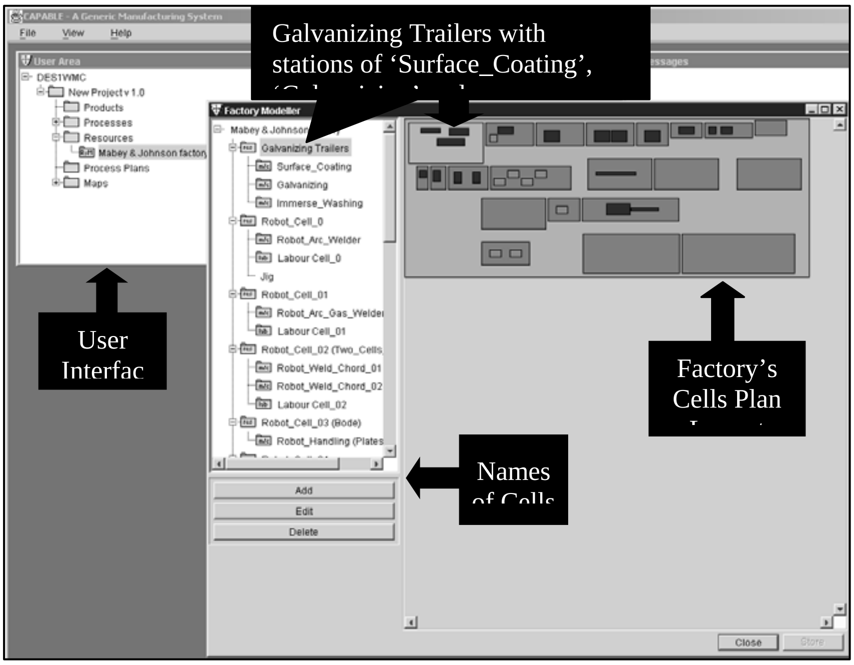


Figure 5: Screenshot of the APPS Factory Model

Resource name	Max. Travel Speed (mm/s)	Max. Weld Flow Rate (mm³/s)	Max. Feeding Velocity (mm/s)	Max Weld Cord Diameter (mm)	Max Loading (kg)	Max Arm length (mm)	Duration (Hrs)
‘IRB 4400’	250	NA	72	NA	60	1950	NA
‘IRB 1400’	250	NA	72	NA	5	1440	NA
‘IRB 340’	100	NA	NA	NA	1	NA	NA
‘IRB 6400PE’	250	3	72	14	120	2500	NA
‘IRB 6400R’	250	3	72	14	500	2250	NA
Galvanising Plant	NA	NA	NA	NA	NA	NA	24

Table 1: Example Resource Model Data

4.4 Process Model

Process modelling is used to identify the type of process needed to assemble the bridge panel. The Process Model provides specific methods which have been developed to calculate manufacturing time and production quality. Resource Modelling is used to specify process parameters for the selected machining centres i.e. to give a range of tools which will be able to perform all necessary operations associated with the product features. Figure 6 shows a user interface of the process model in the APPS. In order to assemble the bridge panel at M&J, other types of processes are also available within the system. These are:

- semi and fully automatic robotic welding,
- manual welding,
- drilling,
- surface coating,
- galvanising,
- immerse washing and inspection.

Furthermore, the company has also imposed Welding Process Specification, Just-in-time and Kanban techniques to improve the shop floor efficiency. Each of the processes and techniques require a high degree of *know-how* to operate successfully.

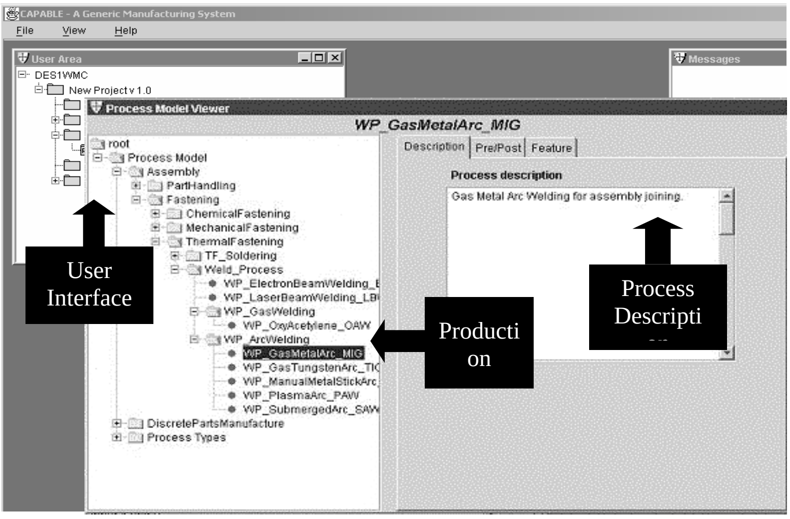


Figure 6: Screenshot of the APPS Process Model

4.5 Aggregate Process Planning for a Single Bridge Panel

The process plan represents a sequence of assembly and subassembly operations for the construction of a single bridge panel. The steps of the assembly sequence of the final product is made up by a number of subassemblies A, B, C, D, E and F as represented in Figure 7. Each of the subassemblies is made up of a number of design feature units as indicated in the diagram. For instance, subassembly A and one unit of vertical beam produced subassembly B. Similarly, subassembly B and one unit of vertical beam produced subassembly C. Once the bill of material for the end product has been prepared, an aggregate process plan can be obtained via the APPS.

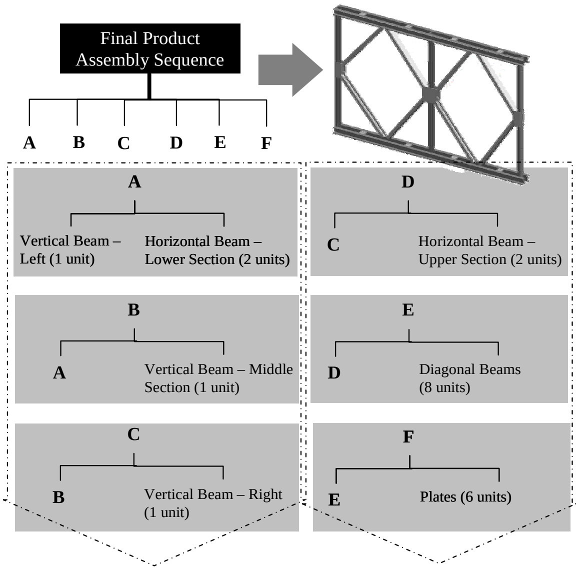


Figure 7: Assembly and Subassembly sequence of a bridge panel

4.6 Manufacturing Knowledge Acquisition and Reuse

4.6.1 Populating the Manufacturing 'Know-how' Knowledge-based system

It is assumed that knowledge acquisition is performed internally by the knowledge experts within M&J Ltd via interviews and paper based information. There are two knowledge types: quantitative and qualitative. The knowledge types are further classified into *Written and Benchmarking*, *Observation and Intuition*, *Employee Tacit and Experience* and *Best Practice* as explained by Cheung et al (2006). Figure 8 represents the Manufacturing Know-how Knowledge-based system (KBS). The KBS consists of three parts: (1) the main body of the structure, (2) user input dialogue and (3) the knowledge instances. The figure illustrates an example of how instances related to a factory are populated and stored in the KBS.

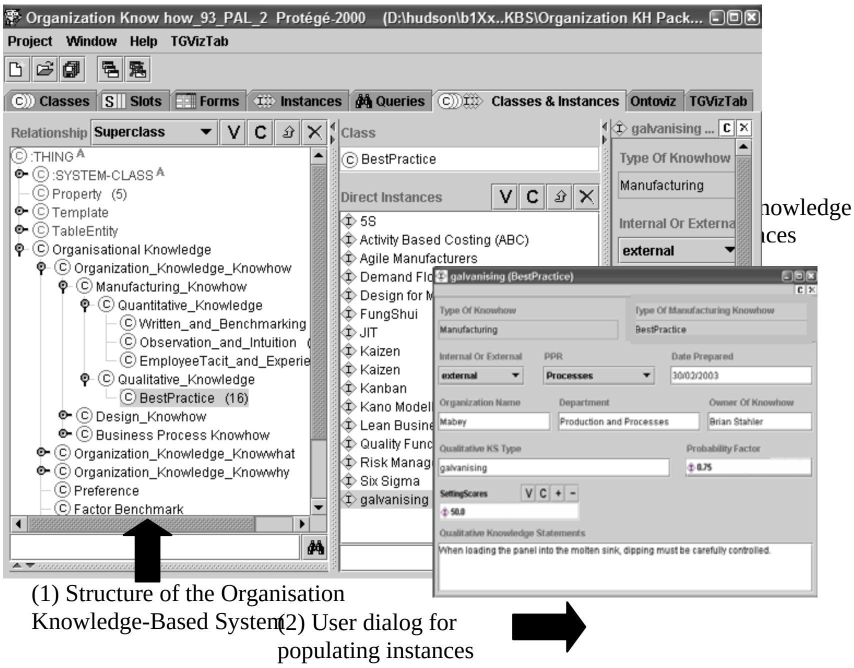


Figure 8: Knowledge Acquisition

One of the most important aspects of creating knowledge statements is setting the value of the *Probability Factor* (Cheung et al, 2006). For instance, *galvanising* is a simple but delicate process and is mostly manually operated which can involve up to six steps to produce the desired coating. Every galvanising '*dip*' takes up to 8 bridge panels at a time. *Dipping speed* varies upon the type of bridge panel and the number of panels going through the molten sink, thus, the *dipping speed* must be carefully controlled to avoid '*air trapped*' when loading the panel into the molten sink (see Figure 8). If the *dipping speed* is too high this may create a sudden explosion due to *'air trapped'*. Since *dipping speed* is so important the associated *Probability factor* constraint which defined by axioms is shown in Figure 9. Hence when the user chooses the value 'always', axioms tells the system how to interpret the imports numerically. In this case, the highest possible value is '1'. This value will then to be used by the capability analysis method (Baker and Maropoulos, 1998). All of these experiences can be stored into the KBS as explicit manufacturing know-how.

```
(exists? Probability
        (and
                (< ('Always'? Probability) 1)
                (< ('Frequently'? Probability) 0.75)
                (= ('Never'? Probability) 0.0)
                (< ('Occasionally'? Probability) 0.25)
                (< ('Sometimes'? Probability) 0.5)
        )
)
```

Figure 9: Example Probability Factors Defined by Axioms

Another example is the application of design know how. Design knowledge, covering several processes and resources, was added into the ontology by the knowledge experts. Subsequently, using the APPS, a process plan was created using feature-to-process and process-to-resource mappings which involved the galvanising process. Taking into account the process parameters (the temperature fluctuation from ambient to 500 °C) the following critical areas of knowledge were immediately identified and presented to the designer:

- Explosions *always* occur if *air trapped* is in the design, for example a closed tube.
- *If Weldments* are present, they should *always* be designed to avoid acid traps
- *Flat panels should normally* be braced to minimise the risk of distortion

These are a few of the examples of using the KBS to capture the expertise to be reused and shared within the product development processes.

4.6.2 Usage of PLM system to store Knowledge

Figure 10 illustrates a sequence of events of how a XML-based knowledge file being stored in a PLM system and subsequently to be downloaded by an external user. The diagram represents:

1. Having created the XML-based knowledge file, the next stage is to invoke the PLM system and use the '*create document*' function to download the knowledge XML-based file into the PLM document storage cabinet.
2. Next is to use the XML document by invoking the PLM '*check-out*' function which downloads the document into the user's local file space.

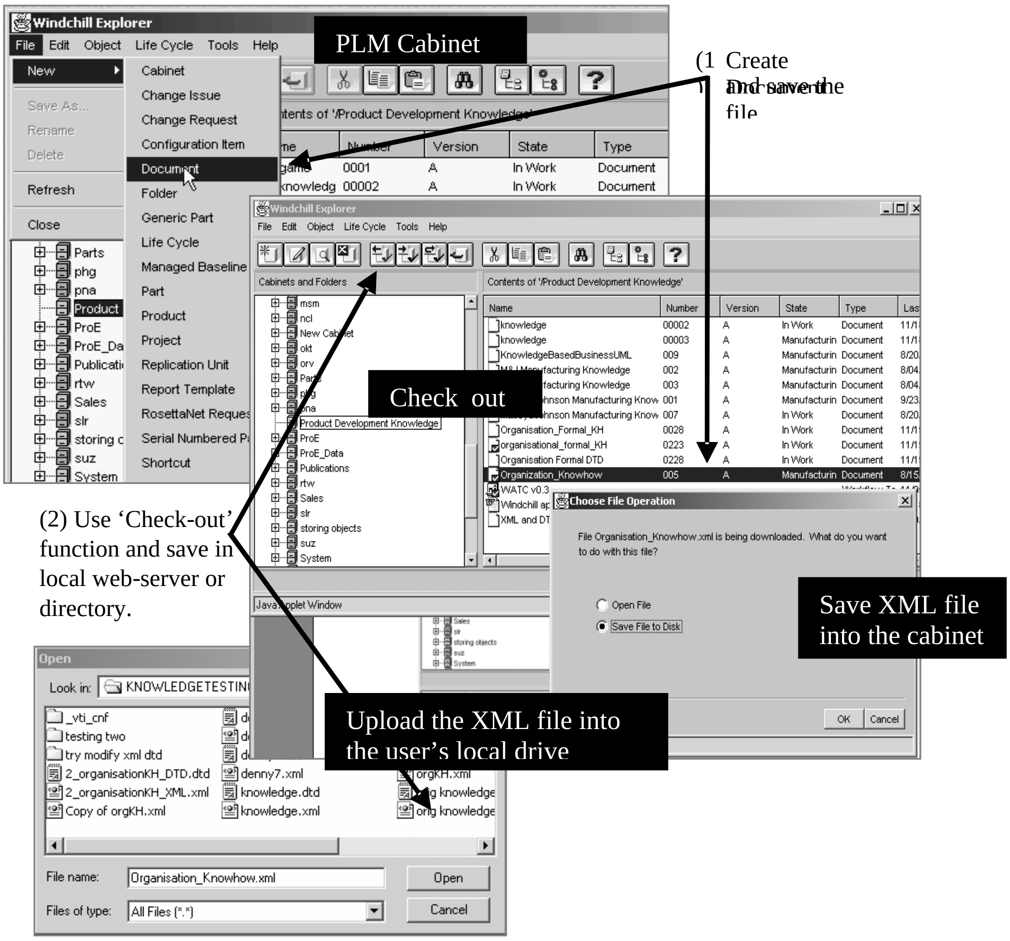


Figure 10: Use of PLM in XML-based knowledge

4.6.3 XML Parser in Knowledge Re-use in Process Planning

This section describes the demonstration of how the application of the XML Parser supports a third party software system. The coordination of the activities is based on the method of WATC. The testing environment is illustrated in Figure 11, which depicts an example of Web-based data interoperability between a knowledge-based system, a PLM system, the APPS and an ERP system. The example shows that the captured knowledge will be saved in a XML file and then placed into a Windchill PLM Cabinet. The diagram also illustrates the links of an XML-based manufacturing knowledge to be re-used by the APPS.

The links were established by the XML Parser and defined by *data-string-type* (*extract XML Metadata).* The *data-string-type* is the term used within the XML Parser to identify the *subject-type* in the XML-based knowledge document. Thus, this allows the extracted data to be transferred to the data models in the APPS. After obtaining an aggregate process plan for the conceptual design with the APPS, this will then transfer into the PLM system and ready to be checked-out into the ERP system for capacity planning.

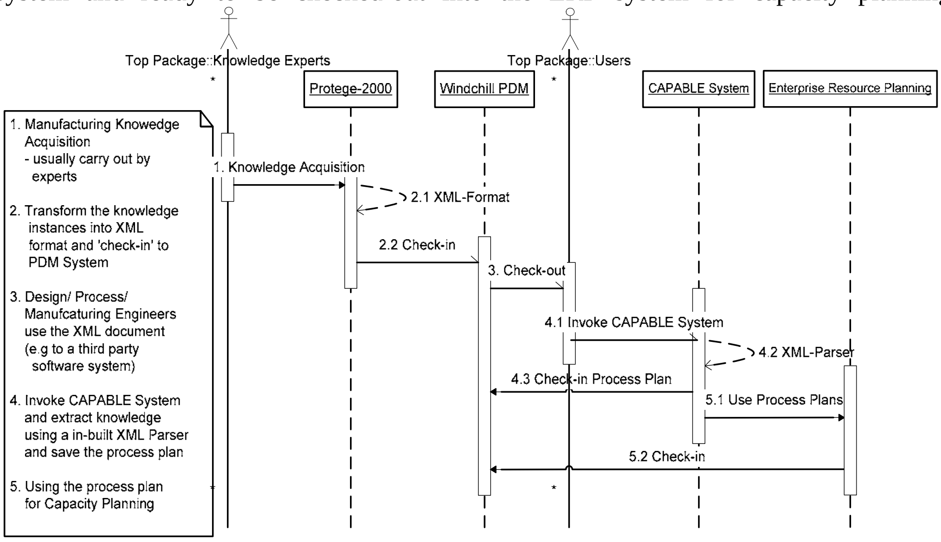


Figure 11: Centralised Testing in UML Sequence Diagrammatic Representation

Figure 12 illustrates the knowledge statements related to a specific object termed Robot_Cell_0 which belongs to a station of a factory. As highlighted in the diagram, in order to refine a conceptual design:

1. from the APPS, a designer will invoke the XML Parser within the data model, for example the factory resource model,
2. the designer will select the XML based knowledge file from the local directory which is already uploaded from the PLM cabinet, and
3. the knowledge statements will then attach to a particular group of machines, which can be used for further analysis to enhance the planning process of a conceptual design. The example shown in Figure 12 indicates the resulting knowledge statements extracted to the APPS which relate to a factory (resource) model object ‘Galvanising Trailer’ which belongs to a cell of “M&J Ltd” factory.

The design engineer is then required to select the relevant knowledge to refine the design and subsequently run the APPS to obtain a preliminary process plan based upon these knowledge factors. If the plan requires review, the prioritised knowledge factors obtained from capability analysis, highlight the most appropriate areas of the process plan for improvement based upon the specific instances of knowledge factors used. If the process plan is acceptable, it is then delivered to the PLM system for Plan/Review, and subsequently is readied for implementation in an ERP System for capacity requirements planning.

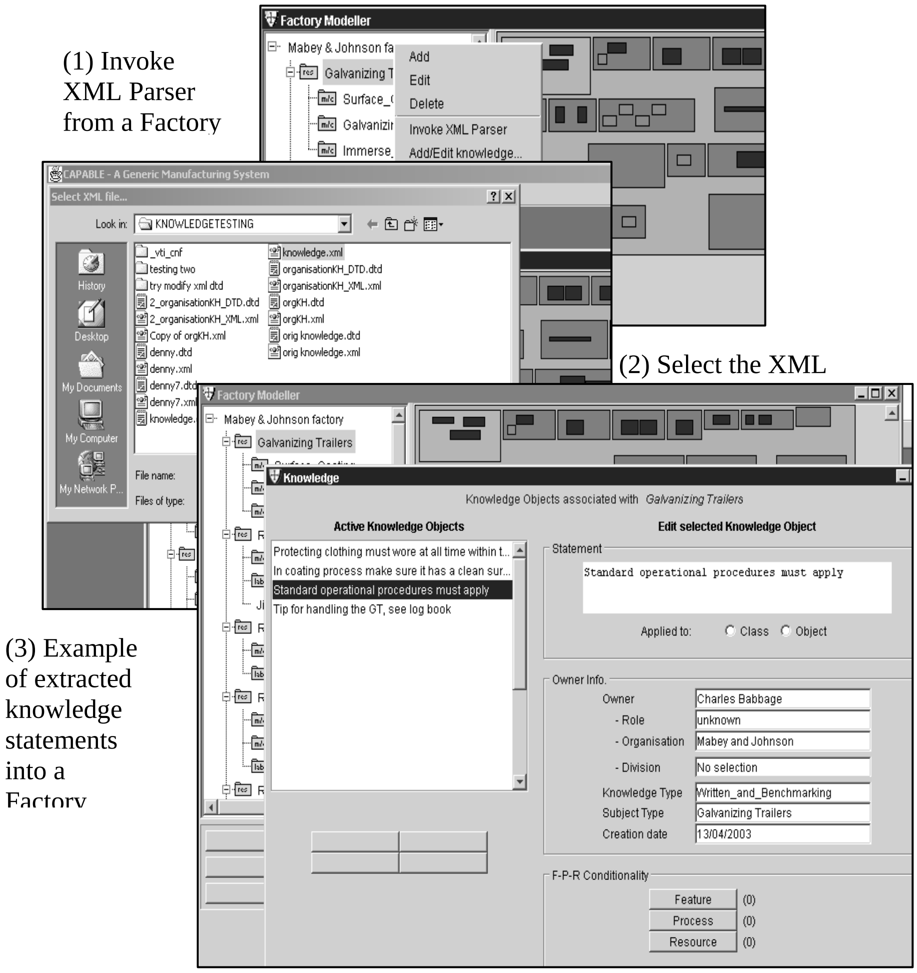


Figure 12: Example knowledge statements related to a specific object

An early process plan is generated by the APPS. However, in order for the ERP system to read and extract the right type of information, the process plan has been converted to a spreadsheet data formatted file. Based on this information the ERP system can estimate the resultant requirements at individual work centres as described in the next section.

4.7 ERP for Capacity Requirements Planning and Testing Results

The ERP system used in this case study is called Compiere. Since the system has many different functions available, the ERP system must be customized. For example, the correspondence functions which uses in the implementation are:

(a) Import File Loader	(b) Resource	(c) BOM drop
(d) Product	(e) Production	(f) Asset

Import the spreadsheet file using the *Import File Loader* function. *Resource* function captures the relevant resource data, such as the machine and station types. *Product* function captures the requirement of product features. *BOM Drop* captures the assembly and process sequences. *Production* captures information related to the *Client (customer)* such as description of the product, production plan, line and date of movement. *Asset* is the final function used to capture detail views of the *resource* requirements such as the availability, location and delivery. Next, fill in all additional information, for example, in the *product* function. Information such as weight, height of the product feature, cost and so on.

The illustration shown in Table 2 indicates the Capacity Requirements Planning generated by the Compiere system. The table illustrates the impact of the time-phased capacity information. The total workload of 1050 hours and its percentage allocations to each workstation over a 10 day period for 50 panels per day. One of the reasons to use a 10 day period is to show the periodic changes according to the manufacturer's Master Production Schedule (MPS) requiremnets. The timing of workcentres varies, for instance, for the workstation *Galvanizing* at time period 2, a capacity requirement was planned for 16.5 hours and *Immerse_Washing* was planned for 7.5 hours. This indicates that the total processing time for the 50 panels in *Galvanising* is 16.5 hours and 7.5 hours in *Immerse_Washing* respectively. Further particulars the table has indicated is the concern of long range capacity planning, thus, the system is able to generate and provide indications of capacity planning requirements for a longer period of time.

	Time Period											
Workstations	1	2	3	4	5	6	7	8	9	10	Total Hours	Workstations Percentage (%)
Robot_Deck_01	0	0	0	0	0	0	0	0	0	0	0	0
Robot_Handling (Beams)	12	12	12	9.5	9.5	17	17	17	18.5	18.5	143	13.6
Robot_Deck_02	0	0	0	0	0	0	0	0	0	0	0	0
Robot_Handling (Plates)	6	6	6	9	9	9	9.5	9.5	9.5	9.5	83	7.9
Robot_Weld_Chord_01	0	0	0	0	0	0	0	0	0	0	0	0.0
Robot_Weld_Chord_02	0	0	0	0	0	0	0	0	0	0	0	0.0
Robot_Arc_Gas_Welder	16	16	16	17.5	17.5	17.5	17	17	20	20	174.5	16.6
Robot_Arc_Welder	16	16	16	17.5	17.5	17.5	17	17	20	20	174.5	16.6
Surface_Coating	7	7	7	7.5	7.5	7.5	8	8	9	9	77.5	7.4
Galvanizing	16.5	16.5	16.5	17.5	17.5	17.5	17	17	20	20	176	16.8
Immerse_Washing	7.5	7.5	7.5	8.5	8.5	8.5	9	9	10	10	86	8.2
Inspection	5	5	5	7.5	7.5	7.5	8.5	8.5	9.5	9.5	73.5	7.0
Manual Drilling	0	0	0	0	0	0	0	0	0	0	0	0.0
Panel_Drilling_1	5	5	5	6	6	6	7	7	7.5	7.5	62	5.9
Manual Weld 01	0	0	0	0	0	0	0	0	0	0	0	0
Total	91	91	91	101	101	108	110	110	124	124	1050	100

Table 2: CRP for a full panel

5 Conclusions and Future Work

Within M&J Ltd, all technical knowledge is tacit and possessed by experts. Due to their increasing business practice with distributed operations and supply networks, it is important for them to be able to control and store this technical knowledge from the early design/concept evaluation stage which in turn could improve the responsiveness to customers. The case study was used to illustrate the concept of bridging the discontinuity in communicating early design concepts and manufacturability evaluations using a centralised network configuration. In essence, the case study has demonstrated the followings:

- Use of enterprise and web-based technologies and the application of an activities co-ordination mechanism which can enhance a distributed and collaborative environment to support the product development process.
- How manufacturing knowledge can be reused by an aggregate process planning system through the application of an automatic data exchange mechanism.
- The performance of supporting the designers to refine a design at the conceptual stage by adding manufacturing knowledge into the APPS to generate alternative

early process plan then use it in an ERP system to obtain and optimised a rough-cut capacity planning

As a result, the methodology demonstrated in this research was used to capture, store and re-use this knowledge within the process of collaborative product development. Specifically:

- Early collaboration in product design using the WATC methodology can maximise the opportunity for optimising designs.
- With the increasing of knowledge in design and manufacturing capabilities, the application of organisational knowledge-based system coupled with the aggregate process planning method can be used to capture and maximise the amount of available information when designing customised products.
- The integration environment using enterprise technologies can enhanced the speed of feedback and used to support decision making and enable the design to be right first time.

How much lead time can be reduced on new product introduction is difficult to measure at this stage as the methodology only tested the early stage of product development processes. Another assumption is that the case study was tested in a single user access environment. As for future work, (1) anther case study should be carried out under several geographical locations, for example, with suppliers and subsidiary companies and, (2) the architecture should be extended to the supply chain area so that lead time of new product introduction can be evaluated.

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